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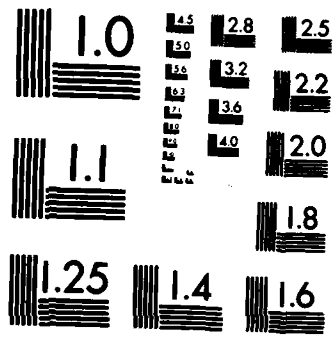


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# Influence of Microturbulence on Early Time HANE Structure

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April 30, 1984

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This document ~~It is shown~~ that microturbulence can have a direct effect on the evolution of interchange instabilities. A simple, two-fluid model of the Rayleigh-Taylor instability is considered which incorporates the effects of microturbulence through anomalous electron-ion and ion-ion collisions. A set of two-dimensional nonlinear mode coupling equations is developed. It is demonstrated that the intermediate wavelength regime of the instability can saturate by transferring energy from the growing modes to the damped modes because of the nonlinear E X B motion. A crucial point in the analysis is that anomalous electron-ion collisions provide the dissipation mechanism for the damped modes. Applications of this theory to early time HANE structuring are discussed.


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INFLUENCE OF MICROTURBULENCE ON EARLY TIME HANE STRUCTURE

## CONTENTS

# INFLUENCE OF MICROTURBULENCE ON EARLY TIME HANE STRUCTURE

## I. INTRODUCTION

An important issue to the Defense Nuclear Agency is understanding the physical processes involved in the structuring of the ionosphere following a HANE. The large-scale, long-lasting ionization irregularities produced by a HANE can adversely impact radar and communications systems (i.e., scintillations). Thus, it is crucial to understand the structuring mechanisms associated with HANES in order to obtain a predictive capability which could aid the operation of these systems in a nuclear environment. Recently, there has been renewed interest in the DNA community concerning early time HANE processes ($t \lesssim$ few sec). For example, DNA is presently funding a major laser experiment at NRL to explore the physics associated with early time HANE evolution.

Among the various early time processes to be understood, the occurrence of plasma microinstabilities and of structure producing processes (i.e., interchange instabilities) are two important areas. To our knowledge, these two areas have been treated somewhat independently of each other. The studies of microturbulence have been directed at explaining the coupling of debris and air plasmas (i.e., momentum exchange), and on the heating of the plasmas (i.e., energy exchange) (Lampe et al., 1975). On the other hand, the studies of early time structuring processes, which have been limited to date, do not directly include microturbulence effects. It should be noted that microturbulent processes have been included indirectly in an early time structure analysis. The work of Brecht et al. (1982) addresses the growth of Rayleigh-Taylor instabilities based upon the conditions prescribed by the microphysics (e.g., thickness, temperature, density within the coupling shell).

The purpose of this report is to suggest a direct effect of microturbulence on the evolution of early time interchange instabilities. Namely, that microinstabilities can provide a dissipation mechanism (via the anomalous transport properties associated with them) which can cause saturation of an interchange instability through a nonlinear mode coupling process. In order to demonstrate this point, we consider a simplified model. We consider a two-fluid plasma model (ions and electrons) which

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incorporates a gravitational field (g) and a density inhomogeneity ($\nabla n$). We develop a set of nonlinear mode coupling equations for this situation and show that the intermediate regime of the instability can saturate by transferring energy from the growing modes to the damped modes because of the nonlinear electron $E \times B$ motion. The crucial point in the analysis is that anomalous electron-ion collisions provide the dissipation mechanism for the damped modes.

The organization of the paper is as follows. In the next section we derive the nonlinear mode equations. In Section III we present the results for a two mode coupling process. Finally, in Section IV we discuss the implications of our theory for early time HANE processes and describe our future efforts in this area.

## II. DERIVATION OF MODE COUPLING EQUATIONS

The geometry and plasma configuration used in the analysis are shown in Fig. 1. We take the ambient magnetic field to be in the z direction ($\underset{\sim}{B} = B\,\hat{e}_z$), and the density to be inhomogeneous in the x direction ($n = n(x)$). The fundamental assumptions used in the analysis are the following. We assume perturbed quantities to be proportional to $\exp[i(k_x x + k_y y - \omega t)]$ with $k_x L >> 1$, $k_y L >> 1$, $k_x \rho_i << 1$, $k_y \rho_i << 1$, and $\omega << \Omega_i$ where $L = (\partial \ell n\, n/\partial x)^{-1}$ is the density gradient scale length $\rho_i = (T_i/m_i)^{1/2}/\Omega_i$ is the mean ion Larmor radius, and $\Omega_i = eB/m_i c$ is the ion cyclotron frequency. We consider a weakly collisional plasma such that $\nu_{ei}/\Omega_e << 1$, $\nu_{ie}/\Omega_i << 1$, and $\nu_{ii}/\Omega_i << 1$ where $\nu_{\alpha\beta}$ represents a collision frequency between the $\alpha$ and $\beta$ species, and $\Omega_e = eB/m_e c$ is the electron cyclotron frequency. Here, the collisions are attributed to wave-particle interactions, i.e., anomalous collisions. Finally, we assume quasi-neutrality ($n_e \simeq n_i$).

The equations used in the analysis are continuity, momentum transfer, and charge conservation:

$$\frac{\partial n}{\partial t} + \nabla \cdot \left( n \underset{\sim}{V}_\alpha \right) = 0 \tag{1}$$

$$0 = -\frac{e}{m_e}\left(-\nabla\phi + \frac{1}{c}\underset{\sim}{V}_e \times \underset{\sim}{B}\right) - v_e^2 \frac{\nabla n}{n} - \nu_{ei}\left(\underset{\sim}{V}_e - \underset{\sim}{V}_i\right) \tag{2}$$

$$\frac{d\underset{\sim}{V}_i}{dt} = \frac{e}{m_i}\left(-\nabla\phi + \frac{1}{c}\underset{\sim}{V}_i \times \underset{\sim}{B}\right) + \underset{\sim}{g} - v_i^2 \frac{\nabla n}{n} - \nu_{ie}\left(\underset{\sim}{V}_i - \underset{\sim}{V}_e\right) - \frac{1}{n m_i}\nabla \cdot \underset{\approx}{\pi}_i \tag{3}$$

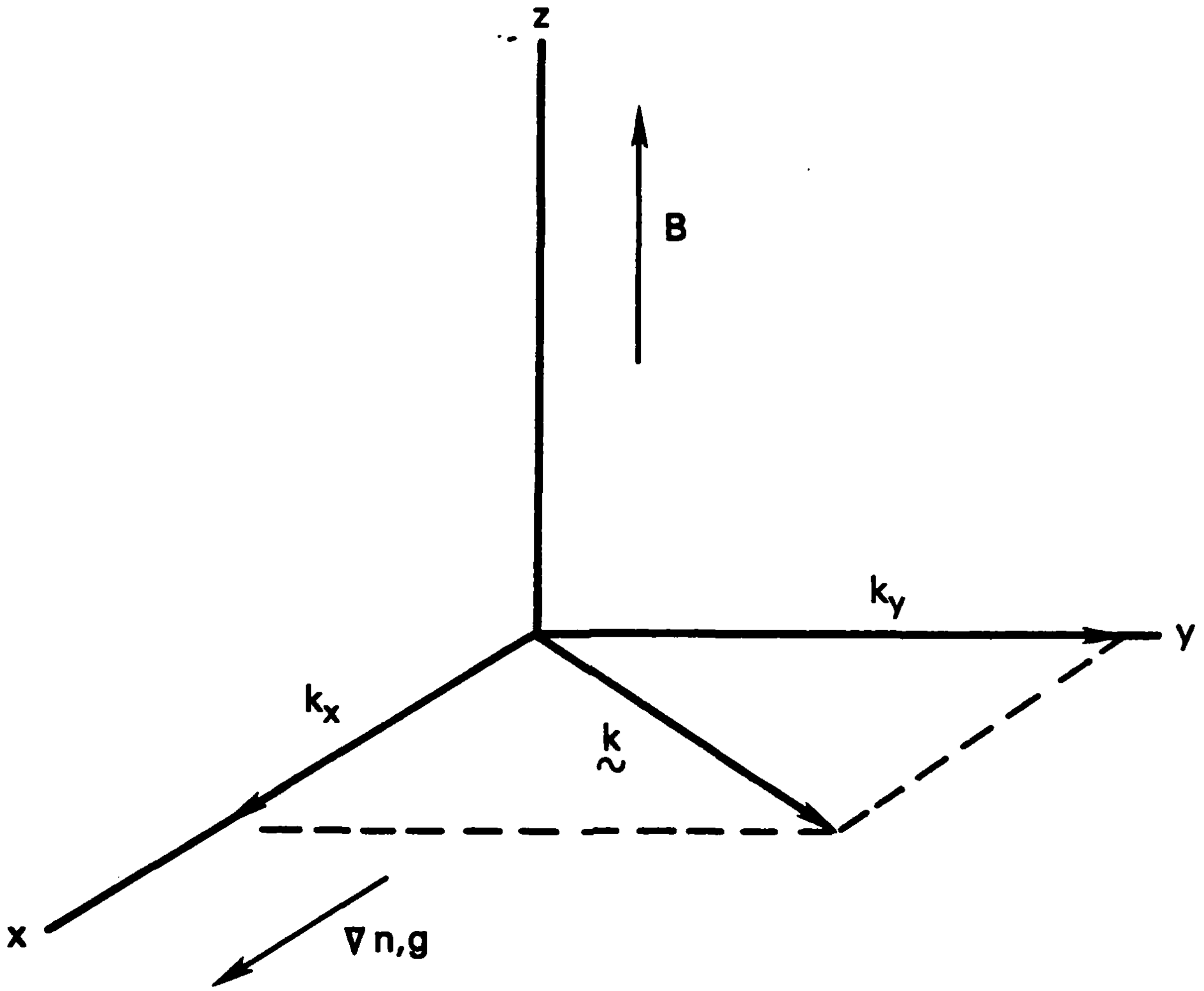


Figure 1: Plasma configuration and slab geometry. The magnetic field is in the z-direction ($\underset{\sim}{B} = B\,\hat{e}_z$), the density gradient and gravity are in the x-direction ($\nabla n = \partial n/\partial x\,\hat{e}_x$ and $\underset{\sim}{g} = g\,\hat{e}_x$), and the wave vector is in the xy plane transverse to B.

$$\nabla\cdot\underset{\sim}{J} = \nabla\cdot\left[n\left(\underset{\sim}{V}_i - \underset{\sim}{V}_e\right)\right] = 0 \tag{4}$$

where $\alpha$ denotes species (e,i), $v_\alpha = \left(T_\alpha/m_\alpha\right)^{1/2}$ is the thermal velocity, and $\underset{\approx}{\pi}_i$ is the ion stress tensor such that (Stix, 1969)

$$\frac{1}{nm_i}\,\nabla\cdot\underset{\approx}{\pi}_i = -\frac{1}{2}\,\Omega_i\rho_i^2\left[\left(\nabla^2 + \frac{\nabla n}{n}\cdot\nabla\right)\underset{\sim}{V}_i \times \hat{e}_z + \left(\hat{e}_z \times \frac{\nabla n}{n}\cdot\nabla\right)\underset{\sim}{V}_i\right]$$

$$- 0.3\;\nu_{ii}\rho_i^2\left[\left(\nabla^2 + \frac{\nabla n}{n}\cdot\nabla\right)\underset{\sim}{V}_i - \left(\hat{e}_z \times \frac{\nabla n}{n}\cdot\nabla\right)\underset{\sim}{V}_i \times \hat{e}_z\right]. \tag{5}$$

The first term in Eq. (5) represents finite ion Larmor radius corrections (Roberts and Taylor, 1962), while the second term represents ion viscosity effects (i.e., shear stress). The compressional stress term in Eq. (5) has been neglected since it is smaller by a factor $k\rho_i$ than the first two terms (Stix, 1969).

To lowest order the equilibrium particle drifts are given by (from Eqs. (2) and (3))

$$\underset{\sim}{V}_{e0} = -\,V_{de}\hat{e}_y \tag{6}$$

$$\underset{\sim}{V}_{i0} = \left(V_{di} + V_g\right)\hat{e}_y \tag{7}$$

where $V_{d\alpha} = \left(v_\alpha^2/\Omega_\alpha\right)\partial\ell n\; n/\partial x$ is the diamagnetic drift velocity of species $\alpha$ and $V_g = -\,g/\Omega_i$ is the ion gravitational drift velocity.

We now perturb Eqs. (1) - (4) about this equilibrium and let $n = n_o + \delta n$, $\phi = \delta\phi$, and $\underset{\sim}{V}_\alpha = V_{\alpha 0} + \delta\underset{\sim}{V}_{\alpha 1} + \delta\underset{\sim}{V}_{\alpha 2}$. Here, $\delta V_{\alpha 1}$ is the first order velocity perturbation and $\delta\underset{\sim}{V}_{\alpha 2}$ is the second order velocity perturbation (i.e., proportional to small factors such as $\nu_{ei}/\Omega_e$, $\nu_{ie}/\Omega_i$, $\nu_{ii}/\Omega_i$, $k^2\rho_i^2$, $\Omega_i^{-1}d/dt$). The first order perturbed velocities are

$$\delta\underset{\sim}{V}_{e1} = -\,\frac{v_e^2}{\Omega_e}\,\nabla\left(\frac{e\delta\phi}{T_e} - \frac{\delta n}{n_0}\right) \times \hat{e}_z \tag{8}$$

$$\delta\underset{\sim}{V}_{i1} = -\,\frac{v_i^2}{\Omega_i}\,\nabla\psi \times \hat{e}_z \tag{9}$$

where $\psi = e\delta\phi/T_i + \delta n/n_0$.

The second order velocities are

$$\delta \underset{\sim}{V}_{e2} = - \frac{\nu_{ei}}{\Omega_e} \frac{v_i^2}{\Omega_i} \left(1 + \frac{T_e}{T_i}\right) \nabla \frac{\delta n}{n_0} \tag{10}$$

$$\begin{aligned} \delta \underset{\sim}{V}_{i2} = & - \rho_i^2 \left(\frac{\partial}{\partial t} + \underset{\sim}{V}_{i0} \cdot \nabla\right) \nabla \psi - \nu_{ie} \rho_i^2 \left(1 + \frac{T_e}{T_i}\right) \nabla \frac{\delta n}{n_0} \\ & + \rho_i^2 \frac{1}{2} \frac{v_i^2}{\Omega_i} \left[\left(\nabla^2 + \frac{\nabla n_0}{n_0} \cdot \nabla\right) \nabla \psi \times \hat{e}_z + \left(\hat{e}_z \times \frac{\nabla n_0}{n_0} \cdot \nabla\right) \nabla \psi\right] \\ & + 0.3\, \rho_i^2 \frac{\nu_{ii}}{\Omega_i} \frac{v_i^2}{\Omega_i} \left[\left(\nabla^2 + \frac{\nabla n_0}{n_0} \cdot \nabla\right) \nabla \psi - \left(\hat{e}_z \times \frac{\nabla n_0}{n_0} \cdot \nabla\right) \nabla \psi \times \hat{e}_z\right] \end{aligned} \tag{11}$$

Substituting Eqs. (8) - (11) into the electron continuity (Eq. (1)) and charge conservation equations (Eq. (4)), we arrive at the coupled set of equations for $\delta n$ and $\delta \phi$

$$\frac{\partial}{\partial t} \frac{\delta n}{n_0} - \frac{v_i^2}{\Omega_i} \nabla \frac{e \delta \phi}{T_i} \times \hat{e}_z \cdot \frac{\nabla n_0}{n_0} - D_e \nabla^2 \frac{\delta n}{n_0} = \frac{v_i^2}{\Omega_i} \nabla \frac{e \delta \phi}{T_i} \times \hat{e}_z \cdot \nabla \frac{\delta n}{n_0} \tag{12}$$

and

$$\frac{g}{\Omega_i} \times \hat{e}_z \cdot \nabla \frac{\delta n}{n_0} - \rho_i^2 \left[\left(\frac{\partial}{\partial t} + \frac{g}{\Omega_i} \times \hat{e}_z \cdot \nabla\right) \nabla^2 - 0.3 \frac{v_i^2}{\Omega_i} \frac{\nu_{ii}}{\Omega_i} \nabla^4\right] \left(\frac{e \delta \phi}{T_i} + \frac{\delta n}{n_0}\right) = 0 \tag{13}$$

where $D_e = \nu_{ei} \rho_{es}^2$ is the electron diffusion coefficient and $\rho_{es}^2 = \left(v_i^2 / \Omega_i / \Omega_e\right)\left(1 + T_e / T_i\right)$.

Thus, Eqs. (12) and (13) represent nonlinear mode coupling equations for the Rayleigh-Taylor instability in the intermediate wavelength regime (i.e., $kL \gg 1$ and $k\rho_i \ll 1$). The physics contained in Eqs. (12) and (13) is described as follows. The second term on the LHS of Eq. (12) leads to growth of the density perturbation while the third term leads to damping because of electron diffusion. The term on the RHS of Eq. (12) is the electron $E \times B$ nonlinearity. The first term on the LHS of Eq. (13) represents the differential motion of the electrons and ions in the y direction because of gravity. The first term in brackets is the ion polarization term while the second term contains ion viscosity effects.

## III. ANALYSIS OF MODE COUPLING EQUATIONS

### A. Linear Theory

We linearize Eqs. (12) and (13) by neglecting the electron E × B nonlinearity in Eq. (12). We assume that perturbations are proportional to $\exp[i(k_x x + k_y y - \omega t)]$. From Eq. (12), it can be shown that

$$\frac{\delta n}{n_0} = - \frac{k_y v_i(\rho_i/L)}{\omega + i\nu_{ei}k^2\rho_{es}^2} \frac{e\delta\phi}{T_i} \tag{14}$$

where $L = (\nabla n_0/n_0)^{-1} = (\partial\, \ell n\, n_0/\partial x)^{-1}$ is the scale length of the density gradient. Similarly, from Eq. (13) it can be shown that

$$- [\omega_g + k^2\rho_i^2(\omega + \omega_g + i\ 0.3\ \nu_{ii}k^2\rho_i^2)]\ \frac{\delta n}{n_0} = k^2\rho_i^2\ [\omega + \omega_g + i\ 0.3\ \nu_{ii}k^2\rho_i^2]\ \frac{e\delta\phi}{T_i} \tag{15}$$

where $\omega_g = k_y g/\Omega_i$. Combining Eqs. (14) and (15), we obtain the linear dispersion equation

$$\omega^2 + b\omega + c = 0 \tag{16}$$

where

$$b = - k_y V_{i0} + i\left(\nu_{ei}k^2\rho_{es}^2 + 0.3\ \nu_{ii}k^2\rho_i^2\right) \tag{17}$$

$$c = - \frac{k_y^2}{k^2}\frac{g}{L} - \left[k_y\rho_i(\rho_i/L)\Omega_i - i\nu_{ei}k^2\rho_{es}^2\right] \times \left[- k_y V_g + i\ 0.3\ \nu_{ii}k^2\rho_i^2\right] \tag{18}$$

and $V_{i0} = V_{di} + V_g$, $V_{di} = v_i^2/\Omega_i L$ and $V_g = - g/\Omega_i$. Equation (16) has the solution

$$\omega = - b/2 \pm \left(b^2/4 - c\right)^{1/2} \tag{19}$$

which is rather messy given the complexity of b and c (Eqs. (17) and (18)). In order to gain insight into the solution of Eq. (19), it is best to consider several limiting cases.

1. Collisionless plasma ($\nu_{ei} = \nu_{ii} = 0$)

In the collisionless limit, the dispersion equation is given by

$$\omega^2 - k_y V_{i0}\,\omega - \frac{k_y^2}{k^2}\frac{g}{L} = 0 \qquad (20)$$

which is a well known result (Roberts and Taylor, 1962). The solution to Eq. (20) is

$$\omega = \frac{1}{2} k_y V_{i0} \pm \frac{1}{2}\left[k_y^2 V_{i0}^2 + 4\frac{k_y^2}{k^2}\frac{g}{L}\right]^{1/2} \qquad (21)$$

In the limit $k^2 V_{i0}^2 \ll 4g/L$, the eigenfrequency is

$$\omega = \pm \frac{k_y}{k}\left(\frac{g}{L}\right)^{1/2} \qquad (22)$$

so that instability results if g and $\nabla n$ are oppositely directed, i.e., $g/L < 0$. On the other hand, in the limit $k^2 V_{i0}^2 > 4g/L$, the mode becomes stable ($\gamma = 0$) and propagating ($\omega_r \sim k_y V_{i0}$). Since it is generally the case that $V_{i0} \simeq V_{di} = (\rho_i/L)v_i$, the stabilization criterion is roughly

$$k^2\rho_i^2 > 4gL/v_i^2 \qquad (23)$$

and is therefore known as 'finite Larmor radius stabilization'. An important point is that the stable modes have $\gamma = 0$ and are not damped, i.e., $\gamma < 0$. This is a crucial consideration in the mode coupling saturation mechanism since damped modes are required as energy sinks.

2. Collisional plasma ($\nu_{ei} \neq 0$ and $\nu_{ii} \neq 0$)

We now consider the strong collision limit given by $\nu_{ii}k^2\rho_i^2 \gg \omega$, $k_y V_{i0}$. For this case the dispersion equation

$$i\omega\, 0.3\, \nu_{ii}k^2\rho_i^2 = \frac{k_y^2}{k^2}\frac{g}{L} + 0.3\, \nu_{ii}k^2\rho_i^2 \nu_{ei}k^2\rho_{es}^2 \qquad (24)$$

which has the solution

$$\omega = - i\left[\frac{k_y^2}{k^2} \frac{g/L}{0.3\ \nu_{ii} k^2 \rho_i^2} + \nu_{ei} k^2 \rho_{es}^2\right] \tag{25}$$

Again instability can result for $g/L < 0$ (oppositely directed g and $\nabla n$) as long as

$$\frac{k_y^2}{k^2} \frac{|g/L|}{0.3\ \nu_{ii} k^2 \rho_i^2} > \nu_{ei} k^2 \rho_{es}^2. \tag{26}$$

In the opposite limit,

$$\nu_{ei} k^2 \rho_{es}^2 > \frac{k_y^2}{k^2} \frac{|g/L|}{0.3\ \nu_{ii} k^2 \rho_i^2} \tag{27}$$

the modes are damped, i.e., $\gamma < 0$. The important point is that the electron-ion collision term provides a dissipation mechanism and can produce modes with a negative growth rate. Hence, anomalous electron-ion collisions can produce damped modes in the collisional limit ($\gamma < 0$). This is in contrast to collisionless finite Larmor radius stabilization which produces stable propagating waves ($\gamma = 0$). Finally, we note the similarity of Eq. (25) to that of the usual collisional Rayleigh-Taylor mode which has a growth rate $\gamma = - (k_y^2/k^2)(g/L\nu_{in})$. In the present case, the quantity $0.3\ \nu_{ii} k^2 \rho_i^2$ replaces $\nu_{in}$ (Hudson and Kennel, 1975).

B. Nonlinear Theory

To illustrate the nonlinear saturation of the Rayleigh-Taylor instability we consider the collisional limit and follow the analysis prescribed in Rognlein and Weinstock (1974). Mathematically, this analysis closely follows that of Chaturvedi and Ossakow (1977), but the underlying physical concepts and applications are substantially different. The equations of interest are

$$\frac{\partial}{\partial t} \frac{\delta n}{n_0} - \frac{v_i^2}{\Omega_i} \nabla \frac{e\delta\phi}{T_i} \times \hat{e}_z \cdot \frac{\nabla n_0}{n_0} - D_e \nabla^2 \frac{\delta n}{n_0} = \frac{v_i^2}{\Omega_i} \nabla \frac{e\delta\phi}{T_i} \times \hat{e}_z \cdot \nabla \frac{\delta n}{n_0} \tag{28}$$

and

$$\frac{g}{\Omega_i} \times \hat{e}_z \cdot \nabla \frac{\delta n}{n_0} + 0.3\ \nu_{ii} \rho_i^4 \nabla^4 \left(\frac{e\delta\phi}{T_i} + \frac{\delta n}{n_0}\right) = 0 \tag{29}$$

where Eq. (28) is the same as Eq. (12) and Eq. (29) follows from Eq. (13) by neglecting ion inertial effects.

Equation (28) is linear and one can obtain a simple relationship between $\delta\phi$ and $\delta n$ based upon it, namely,

$$\frac{e\delta\phi}{T_i} = - i \Gamma \frac{\delta n}{n_0} \tag{30}$$

where

$$\Gamma = - \frac{g}{0.3 \nu_{ii} k^2 \rho_i^2} \frac{k_y \Omega_i}{k^2 v_i^2} \tag{31}$$

and we have assumed $k_y L > \Omega_i / \nu_{ii}$.

Equation (27) is nonlinear and can be rewritten as

$$\frac{\partial}{\partial t} \frac{\delta n}{n_0} = \gamma \frac{\delta n}{n_0} + \frac{v_i^2}{\Omega_i} \nabla \frac{e\delta\phi}{T_i} \times \hat{e}_z \cdot \nabla \frac{\delta n}{n_0} \tag{32}$$

where $\gamma$ is the net linear growth (or damping) of modes. The term $\gamma$ results from a combination of the second term on the LHS of Eq. (28) (the growing term) and the third term on the LHS of Eq. (28) (the damping term), and is given by

$$\gamma = \frac{k_y^2}{k^2} \frac{|g/L|}{0.3 \nu_{ii} k^2 \rho_i^2} - \nu_{ei} k^2 \rho_{es}^2 \tag{33}$$

for $g/L < 0$.

We substitute a two-dimensional perturbation of the form

$$\frac{\delta n}{n_0} = A_{1,1} \sin\left(k_y y - \omega t\right) \cos k_x x \tag{34}$$

and (from Eq. (29))

$$\frac{e\delta\phi}{T_i} = \Gamma A_{1,1} \cos\left(k_y y - \omega t\right) \cos k_x x \tag{35}$$

into the nonlinear term of Eq. (32). This procedure yields the following result

$$\frac{v_i^2}{\Omega_i} \nabla \frac{e\delta\phi}{T_i} \times \hat{e}_z \cdot \nabla \frac{\delta n}{n_0} = \frac{g}{0.6\ \nu_{ii} k^2 \rho_i^2} \frac{k_y^2}{k^2} k_x A_{1,1} \sin 2\, k_x x, \tag{36}$$

that is, a second spatial harmonic in the x-direction (along the density gradient) is produced. Thus, we consider a general perturbation of the form

$$\frac{\delta n}{n_0} = A_{1,1} \sin\left(k_y y - \omega t\right) \cos k_x x + A_{2,0} \sin 2\, k_x x \tag{37}$$

Substituting Eq. (37) into Eq. (32) and making use of Eq. (30), we arrive at the following set of coupled nonlinear differential equations for the mode amplitudes

$$\frac{\partial}{\partial t} A_{1,1} = \gamma_{1,1} A_{1,1} - \alpha\, A_{1,1} A_{2,0} \tag{38}$$

and

$$\frac{\partial}{\partial t} A_{2,0} = \gamma_{2,0} A_{2,0} + \frac{\alpha}{2} A_{1,1}^2 \tag{39}$$

where the coupling coefficient is

$$\alpha = k_x \frac{k_y^2}{k^2} \frac{g}{0.3\ \nu_{ii} k^2 \rho_i^2} \tag{40}$$

The mode $A_{2,0}$ is linearly damped (i.e., $\gamma_{2,0} < 0$) which is clear from Eq. (33) since $k_y = 0$ for this mode. Thus, the action of the nonlinear $E \times B$ term is to transfer energy from a growing mode ($A_{1,1}$) to a damped mode ($A_{2,0}$) via a mode coupling interaction. This is shown schematically in Fig. 2. It is possible then to set up a steady state situation such that $\partial A_{1,1}/\partial t = 0$ and $\partial A_{2,0}/\partial t = 0$. One can show that this results in the following set of steady state amplitudes

$$A_{2,0} = \frac{\gamma_{1,1}}{\alpha} \simeq \frac{1}{k_x L} \tag{41}$$

and

$$A_{1,1} = \left(- \frac{2|\gamma_{2,0}|}{\alpha} A_{2,0}\right)^{1/2}$$

$$\simeq \left(\frac{k^2}{k_y^2} \frac{\nu_{ei} k^2 \rho_{es}^2 \cdot 0.3\, \nu_{ii} k^2 \rho_i^2}{gLk_x^2}\right)^{1/2} \qquad (42)$$

We point out that for $|\gamma_{1,1}| > |\gamma_{2,0}|$, one finds that $A_{2,0} > A_{1,1}$ so that the damped modes can be nonlinearily driven to larger amplitudes than the linear driven modes. These results are similar to those of Rognlein and Weinstock (1974), Chaturvedi and Ossakow (1977) and Chaturvedi and Ossakow (1979). Finally, although a rather simple two-mode analysis has been presented, numerical simulations using many modes for both the collisional Rayleigh-Taylor and E × B instability are consistent with this analysis (Keskinen et al., 1980a,b).

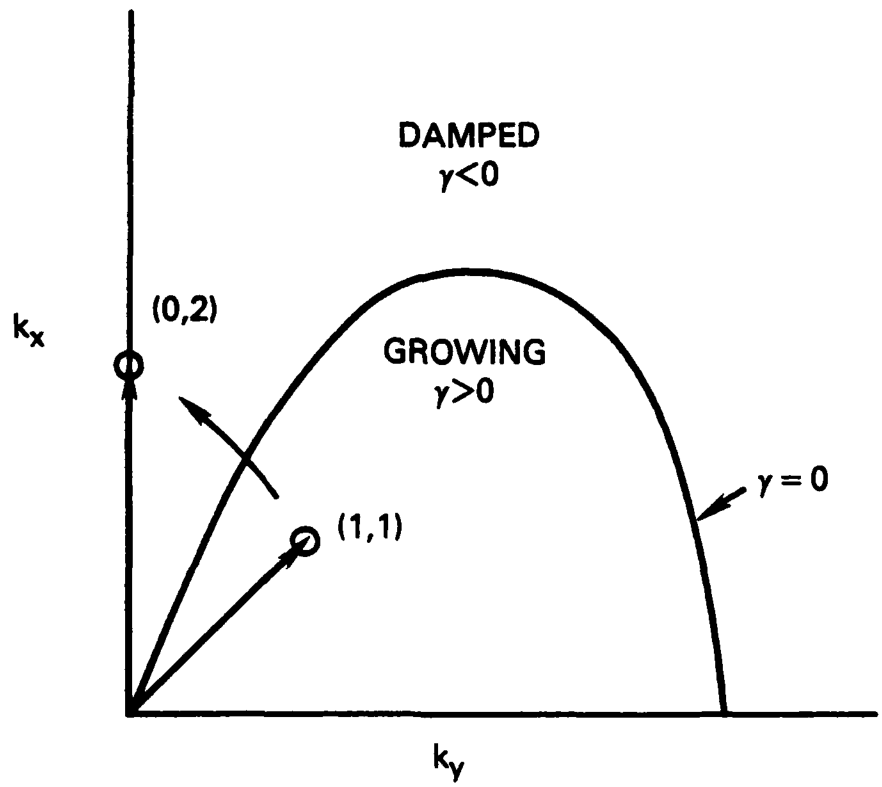


Figure 2: Schematic of mode coupling process. The growing and damped modes are shown in k space. The coupling of the growing (1,1) mode and the damped (0,2) mode is also shown.

## IV. DISCUSSION

The purpose of this paper has been to suggest an important influence of microturbulence on the early time structuring of a HANE. We consider the question, how do anomalous collisions produced by microturbulence affect the development of interchange instabilities? To answer this question, we have adopted a simple two-fluid model of the intermediate wavelength Rayleigh-Taylor instability as a test problem. Specifically, we have developed a two-dimensional nonlinear mode coupling theory of the Rayleigh-Taylor instability in the presence of microturbulence. The primary effect of the microturbulence is to generate anomalous collisions between electrons and ions, as well as ions and ions; an effect considered to be very important in the early time evolution of a HANE. Examples of instabilities investigated for early time HANE applications are the ion-ion counter-streaming instabilities, the modified-two-stream instability, the ion acoustic instability, and the beam cyclotron instability (Lampe et al., 1975). Lampe et al. (1975) have shown that these instabilities can produce significant anomalous collisions between particles, e.g., $\nu_{ei} \lesssim \omega_{pe}$ for the modified two stream and $\nu_{ii} \lesssim \omega_{\ell h}$ for the magnetized ion-ion counter-streaming instabilities where $\omega_{pe}$ is the electron plasma frequency and $\omega_{\ell h}$ is the lower hybrid frequency. We note that in the model considered, the concept of anomalous ion-ion collisions for a single ion fluid is unclear, i.e., anomalous collisionless viscosity is not well understood, but it is a valid concept for a multi-ion species plasma. Thus, as noted in the introduction, the problem addressed in this paper should be considered as an idealized test problem which highlights a potentially important effect in early time HANE physics.

The major result of this work is that the intermediate wavelength modes of the Rayleigh-Taylor instability can be stabilized via a mode coupling process in the collisional regime. Basically, wave energy is transferred nonlinearly from growing modes to damped modes, and a steady state can result. Anomalous electron-ion collisions play a crucial role in that they provide a dissipation mechanism which produces a set of damped modes. This is in contrast to stabilization of the instability due to finite Larmor radius effects which does not produce damped modes, but rather propagating modes with $\gamma = 0$.

A considerable amount of work remains to be done on this problem. Within the context of the simple model developed in this paper two avenues of research are presently being pursued. First, numerical analysis is underway to consider the many-mode situation which is more realistic. In this analysis, a pseudo-spectral code is being used which has proved valuable in understanding the mode coupling stabilization of the lower-hybrid-drift instability (Drake et al., 1983a,b). Second, the effects of ion inertia need to be included self-consistently to understand the transition from the collisionless to collisional regime. Again, the numerical techniques being used allow for this.

While the above described work will provide a better understanding of the nonlinear stabilization of the Rayleigh-Taylor instability, it does not directly apply to early time HANE phenomena. It does provide insight into potentially important effects, and the development of relevant numerical tools. However, considerably different models need to be developed for early time HANE behavior. The types of issues that should be addressed are as follows:

1. A stability analysis of early time HANE has been performed by Brecht and Papadopoulos (1979). They considered the development of a Rayleigh-Taylor instability driven by forces associated with laminar-like acceleration of ions within the coupling shell and with the curvature of the magnetic field lines. Another effect not considered in Brecht and Papadopoulos (1979) is the deceleration of the coupling shell due to line tying currents to the conducting ionosphere (Pilipp, 1971; Fedder, 1980) which could also lead to a Rayleigh-Taylor instability. The point is that there are several mechanisms that could produce early time structure instabilities and that a nonlinear analysis of these instabilities, incorporating microturbulence via anomalous collisions, is warranted. However, this is somewhat more complicated than the present calculation since at least two ion species are required in the analysis, and electromagnetic effects may need to be included.

2. Another possibility for the generation of structure (i.e., density irregularities) in early time HANE is the onset of the Richtmeyer-Meshkov instability (Richtmeyer, 1960; Andronov et al., 1976). This instability grows linearly with time, as opposed to exponentially, and can occur when a

shock wave passes through an irregular (corrugated) interface from a less dense to a more dense fluid. The turbulence generated from this instability may also be influenced by microturbulence, as in the case of the more standard interchange instability case.

3. It has also been suggested that the weapon debris is ´pre-structured´ by the ´nuts and bolts´ of the device itself (Chesnut, private communication). The subsequent evolution of this structure could also be affected by microturbulence. For example, the wavenumber spectrum of the turbulence could be altered by the microturbulence through a mode coupling process.

In conclusion, we have shown that microturbulence, via its associated anomalous collisional effects, can influence the nonlinear development of the collisional Rayleigh-Taylor instability. Namely, it can lead to the stabilization of the intermediate wavelength modes through a two-dimensional mode coupling process. Anomalous electron-ion collisions provide the needed dissipation mechanism. Thus, microturbulence could play an important role in the development of structure for early time HANE phenomena. We have given some examples of the structure problems that could be affected by microturbulence and are relevant to early time HANE processes. Admittedly, some of these ideas are speculative at this time, but it is clear that further research is needed in this area.

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